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Extending the scope of future learning factories by using synergies through an interconnection of sites and process chains

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Abstract

Learning factories serve as platforms to disseminate research findings into industrial practice and to educate prospective engineers in hands-on courses. The number of competences which can be taught in learning factories is related with the number of available processes and machines. A larger number of machines enables for example comparisons between similar processes, the operation of longer process chains and generally speaking a broader curriculum. However, due to financial or space restrictions the investment in machines is often limited. In order to overcome this issue, the collaboration between learning factories through interconnection of process chains is proposed in this paper. A systematic method, by which possible interlinkages can be found, is presented and a case study of the interlinkage of two learning factories in Bayreuth and Augsburg is given.

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1. Introduction

Today's drivers in manufacturing are, amongst others, globalization, changes in demographics, shorter product cycles, greater number of product variants, resource efficiency ambitions and the penetration of internet of things technologies [1]. To cope with these challenges, the competency-level of employees plays a crucial role. In order to improve those competencies, several options for learning exist. Compared to learning through e.g. lectures, students in practical courses of learning factories can gain a greater degree of action substantiating knowledge [2].

Over the past decade several such learning factories have been established by universities, manufacturing companies as well as consulting companies [3]. At the same time, the

cooperation between the learning factories was extended during this period. Apart from the annual Conference on Learning Factories, three collaboration networks shall be mentioned here: First, the Network of Innovative Learning Factories was founded in 2013. One of its main goals is to support the mobility of researchers and students to enable dialogues and find joint solutions to common questions. Second, the CIRP Collaborative Working Group on Learning Factories was founded in 2014 in order to “gather knowledge of the global state-of-the-art, and to generate input for further research programs and collaboration models.” [4]. Third, the WGP Produktionsakademie was established in 2015 to offer and refine a comprehensive training catalogue for researches and industry customers.

Those collaboration networks stimulated significant advances concerning the understanding of the term learning factory, the classification of learning factories and guiding methods for developing new concepts [5, 6]. Despite the active exchange between the operators of learning factories, none or very few of the process chains of the learning factories are interlinked according to the authors knowledge. However, such interlinkage might benefit the individual locations greatly, because usually learning factories have tight constraints concerning either the spatial expansion and/or the financial resources, which limit the number of different machines and processes. By connecting the process chains of two or more learning factories, process chains can be extended, similar technologies can be compared and new process steps such as quality controls or analysis tools can be inserted into an existing chain.

In this paper such linking possibilities and its advantages shall be described on a general level and several application examples are given for the potential interlinkage of the Green Factories Bavaria in Bayreuth and Augsburg.

2. Methodology

Learning factories have the goal to generate learning content that is of high relevance for industry practitioners and students. For that purpose a learning environment needs to be set up which is as close to reality as possible, while balancing specificity and generalizability. Therefore today's learning factories outline their learning content along a specific process chain.

However, these environments increasingly strive to meet the changing requirements of their training participants as well as to address new target groups. Consequently, flexibility and adaptability have already become key success factors for existing learning factories. Hence the question arises: How can existing learning factories identify new possibilities to expand and adapt the scope of their existing learning content?

For that purpose, this chapter proposes a concept how to identify and use possible synergies between different learning factory sites. The procedure consists of the five steps abstraction, identification, evaluation, design and implementation (see Fig. 2).

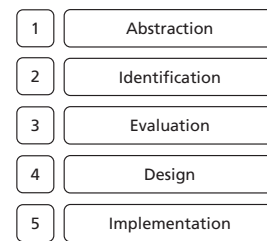


Fig. 2 Procedure model

2.1. Abstraction of learning factory environments

In Fig. 1 a systems analysis approach is chosen in order to abstract factory environments and processes. As a result, the subcategories in learning factories for industrial engineering with a special focus on resource efficiency (LF 1 to LF n) can be identified and generalized. Beside specific process steps (P1.1 to P1.n), cross-sectional technologies (e.g. intralogistics, quality control, analysis tools etc.), auxiliary processes (e.g. compressed air, conditioning of cooling lubricants etc.) and technical building services have been identified. Systems analysis is also useful on the process step level in order to identify flows of energy, material and auxiliaries. Following the procedure model proposed in **Fehler! Verweisquelle konnte nicht gefunden werden.**, abstraction is followed by the identification of possible synergies between existing learning factory environments. For that purpose, four specific options have been identified and are described in more detail in section 2.2. In a consecutive step the visibility of the identified interconnections and synergies is evaluated. This can be done

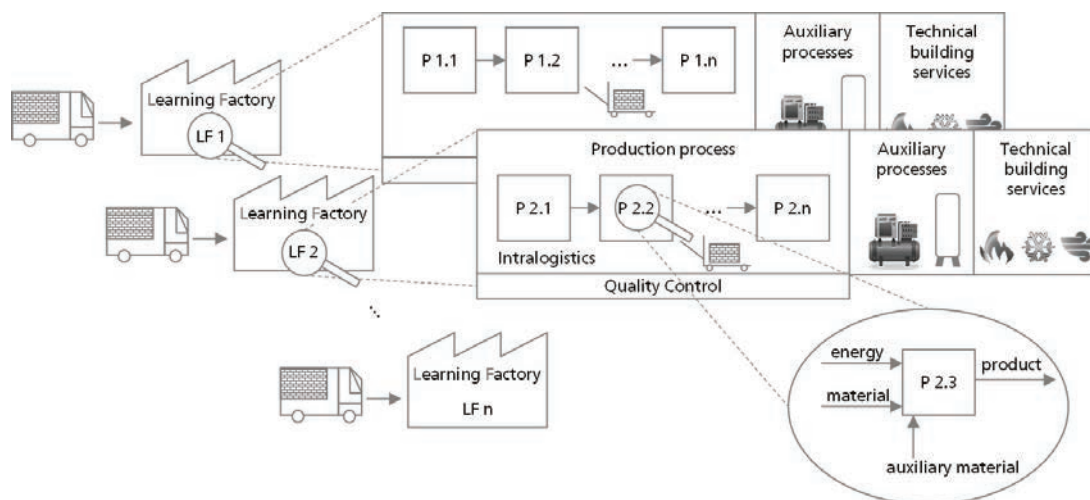


Fig. 1 Abstraction of learning factory environments

by expert interviews in combination with a point rating system for instance. Following the evaluation learning content and practical learning scenarios need to be design. And last but not least the newly designed learning content and additional learning scenarios need to be implemented at the particular learning factory site.

2.2. Identifying options for action

Considering the possibilities for collaboration between different learning factories, four possibilities can be distinguished (ref. Fig. 3).

The first option is to diversify a specific process step of an existing learning factory by comparing different technical solutions (e.g. machine or equipment) that fulfill the same or a similar function. For instance, a process step “cleaning” can be technically realized by the use of a flow or a mechanical based cleaning process. Among others, a process step “hardening” can be realized by an inductive, radiation or convection based hardening process. The availability of different technical solutions for the same process step at different learning factory sides can assist in the diversification of learning contents. For instance different operating principles can be compared with regard to their specific resource consumption.

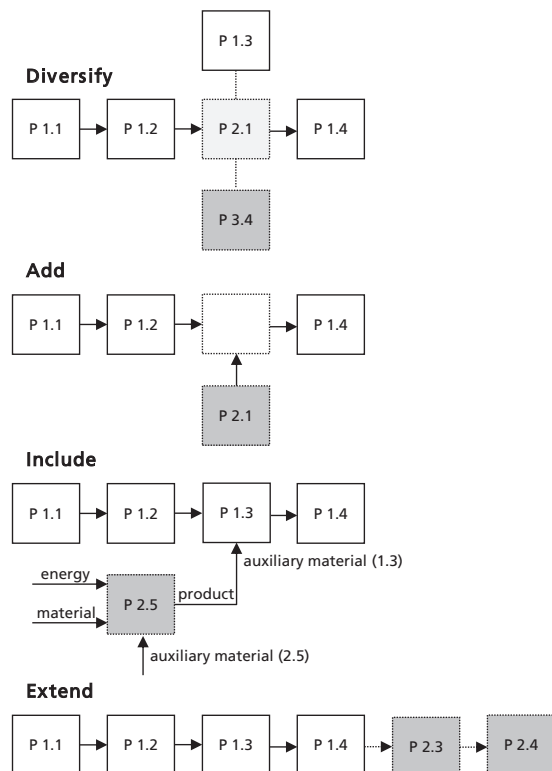


Fig. 3 Options to interlink the process chains of two learning factories

The second option is to add a process that has not been implemented yet in an existing learning factory. This opportunity for collaboration also encompasses the exchange and sharing of knowledge on cross sectional technologies like

quality control or specific analysis tools, auxiliary processes like a cooling network or alternative design of compressed air systems. Hence, equipment and related knowledge that is available at one learning factory side can be shared and used to expand the learning content and scenarios at another site.

The third option is to make the demonstration part or respectively the product of one learning factory become a useful auxiliary material or part for another learning factory.

The fourth option is to extend an existing process chain with processes that have not been considered in the existing learning factory so far. For instance a process step “packaging” is not part of the original learning factory design, yet the knowledge is available at another site and would add value to a training through augmented process know how and the consideration of further life cycle aspects.

The consideration of supply chains as indicated in Fig. 1 can be imagined as another opportunity for collaborations between learning factory sites. However an evaluation of the concepts feasibility still needs to be carried out.

In general, the added value for training participants can be derived from the offer of widespread process know-how and the increased consideration of lifecycle aspects (ref. Fig. 4).

The application of the proposed model suggest that a multiple use of learning factory resources and knowledge can be achieved by a systematic analysis of interfaces between learning factory sites and specific processes. Hence, operators of learning factories can offer an expanded range of learning contents and apply it in a modular way without undertaking costly investments in new equipment.

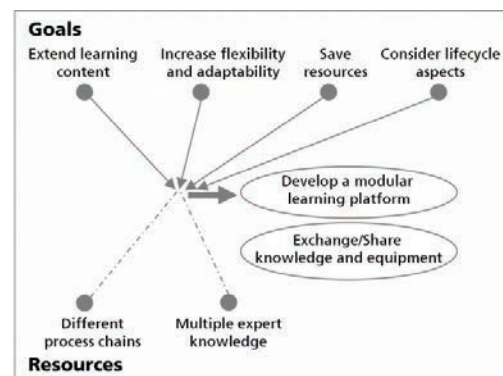


Fig. 4: Matching goals and resources for a sustainable development of learning factory environments.

Applying the suggested method, variable possibilities to use synergies between different learning factory sites can be identified. Following steps three and four of the proposed procedure from Fehler! Verweisquelle konnte nicht gefunden werden. consequently leads to the evaluation and design of new learning contents. Some specific use case applications from the Green Factory Bavaria will be discussed in the next section.

3. Case Study

This section gives a short introduction to the learning factories operated by the authors and their respective process chains. Based on the approach to interconnect those process chains, opportunities concerning the resulting learning contents are derived and discussed.

3.1. Composite process chain at Green Factory Bayreuth

At the learning factory in Bayreuth the manufacturing process for lightweight products made from CFRP has been selected as a reference process. The associated manufacturing steps are shown in Fig. 5. They encompass the production of required auxiliary material like molds and tools, the cutting of the “prepreg” material (pre-impregnated carbon fiber based fabric) so as to obtain processable plies as well as the placement of the plies onto the mold.

Besides curing in an autoclave, manual demolding, mold cleaning as well as assembly and finishing operations are represented as part of the learning factory environment.

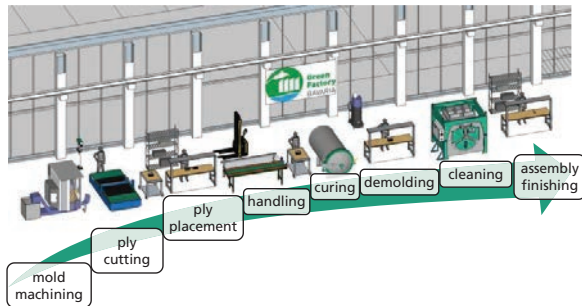


Fig. 5 Process chain of the Green Factory Bavaria in Bayreuth

Based on the reference process several learning scenarios and didactical concepts are already in place, such as the comparison of electrical power consumption in the mold production using different source materials or the identification and adjustment of the power consumption in the different components of a cutter. In this case the training participants are involved through game based learning methods. [7, 8] Besides cross sectional technologies, extraction and assembly tools are demonstrated in a hands-on manner with exemplary workstations [9].

3.2. Additive process chain at Green Factory Augsburg

The process chain of the Green Factory Bavaria in Augsburg is displayed in Fig. 6 [10]. It focuses on the production of a metal gear wheel through additive manufacturing technology [11]. Apart from the core selective laser melting step, the subsequent post-processing steps including cleaning and packaging are considered as well. Moreover it is investigated, how energy inefficiencies can be detected intelligently and how renewable energy plants can be incorporated into the energy supply of a factory [12].

Within the research project it is investigated how to make the individual processes more resource efficient. Among other things the deterioration of the powder quality due to transport, storage and recycling is examined in detail in order to decrease the future powder consumption. Moreover, the cleansing power of biological and chemical detergents is inspected in order to adequately configure such processes. Another topic is intelligent energy monitoring, which aims at identifying energy inefficiencies quickly and automated through the application of machine learning methods.

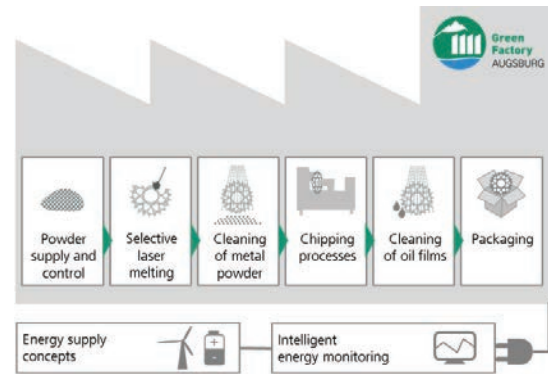


Fig. 6: Process chain of the Green Factory Bavaria in Augsburg

3.3. Mold Manufacturing

Collaboration by diversification enables the comparison of alternative technologies for a process step. For an exemplary application, this interconnection between process chains is applied to the fabrication of a mold which serves as a tool for a composite curing process. The mold fulfills several functions: Transfer of pressure from the press to the work piece; heating of the work piece by means of integrated heating cartridges and the cooling of the work piece by means of a cooling fluid flow. For the production of the mold, two manufacturing processes can be applied: The mold can be created through milling and drilling technologies at the learning factory site in Bayreuth and through laser beam melting (LBM) at the learning factory in Augsburg. In the LBM process, metallic powder materials are consolidated layer-by-layer through selective laser exposition, enabling a high degree of geometric part complexity. Comparing the two manufacturing processes, the specific advantages can be pointed out and compared. In this case, the design of cooling channels can be significantly improved using LBM, since cavities are no longer limited to straight holes. Thus longer cooling channels can be integrated near the surface of the mold and hence optimizing the cooling rate (ref. Fig. 7).

However, cost analysis of the two processes show lower manufacturing costs for the combination of milling and drilling. Therefore a trade-off situation becomes clear between manufacturing cost and product performance, which can be further elaborated on depending on learning objectives. Due to the interconnection of learning factories and process chains, a technology comparison is enabled that shows the specific advantages of the alternatives provokes a trade-off situation that can be the basis for further selection decision evaluation.

This example not only represents the possible diversification of processes (see Fig. 3), but also the extension of process chains since the additive part manufactured in the process chain in Augsburg is used in the process chain in Bayreuth.

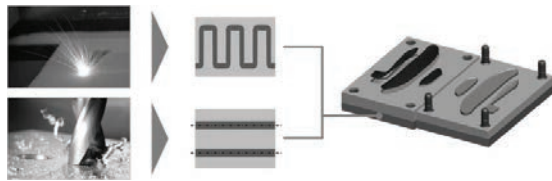


Fig. 7 Cooling channel design; comparison of LBM with conventional manufacturing

3.4. Contamination analysis

Both process chains contain a cleaning step to remove contaminations such as oil. Due to the limited knowledge about the process physics, a large safety margin is usually applied to the process parameters resulting in a high resource consumption. Hence, in order to improve the resource efficiency, one goal is to gain a better understanding of the process physics [13]. This requires the analysis of the cleanliness of the parts, so both groups have invested in analysis equipment.

The device in Bayreuth is able to quantify the total residual amount of fluids on cleaned parts. The device in Augsburg takes advantage of the fluorescent properties of cooling lubricants to detect on which areas lubricant is left (see Fig. 8).

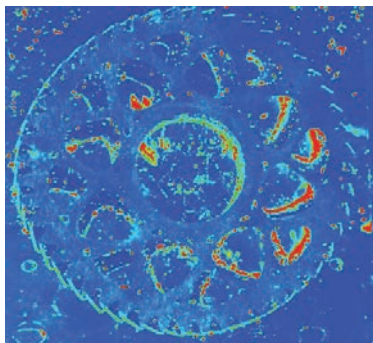


Fig. 8: Detection of remaining cooling lubricant on a gear wheel through fluorescence

Since the analysis devices are based on different detection mechanisms, it would be beneficial for prospective students to use the respective other device as an additional process step.

4. Outlook

In the near future the authors strive to put the given examples into action, thereby extending their access to different processes and machines and strengthening the collaboration between the two sites. Future research activities also try to establish virtual reality (VR) and virtual learning as a means of divulgation and easy access to learning content and

scenarios through a cloud based knowledge database (ref. Fig. 9). This is also because future learning factories require the capability to adapt to upcoming research topics, for instance technologies that are based on the concepts of cyber-physical systems and the internet of things [14]. This development is foreseen to have great potential also because prices for VR-hardware and equipment have experienced a major cost reduction [15].

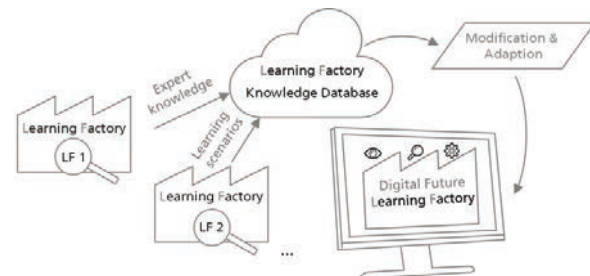


Fig. 9 Virtual learning in Learning Factories of the Future

Additionally, virtual learning environments (VLE) respond to the mostly unconsidered aspect of occupational safety in existing “physical” learning factories. Yet, corresponding research questions need to be given attention and addressed in upcoming research activities.

Q 1: How can hands-on learning experience in a near-industry environment be made available while respecting all aspects of occupational safety?

Q 2: Does virtual learning present an effective alternative to the experience in a “physical” learning environment?

5. Conclusion

The authors of this paper advocate the interlinkage of learning factory process chains in order to overcome financial and space constrictions. It distinguishes between four types of interlinkages, diversification, addition, inclusion and extension and proposes a systematic method of how to identify and implement an interlinkage between two learning factories. Finally, several examples are given in the case study, in which possible ways of cooperation between the process chain of the learning factories in Augsburg and Bayreuth are explained. In addition, future challenges for existing learning factories and the opportunities through virtual learning are outlined.

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